Living With a Star

Support to
Human Space Flight
and
Human Exploration and Development of Space

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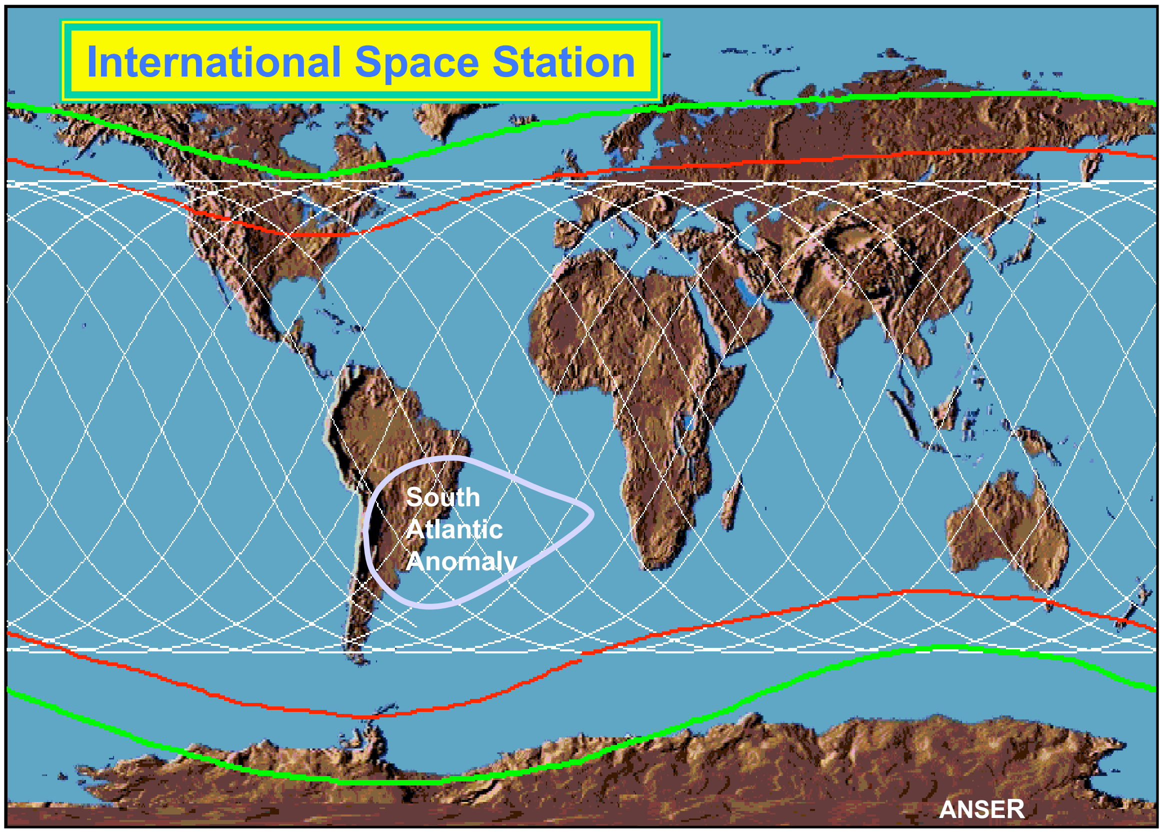
Objective

- What is the threat posed by SPEs
- How can LWS advance the state of the art in SPE forecasting
- What will be the impact of these advances
- What components may contribute to an improved SPE risk mitigation system

Astronauts Are Exposed to Radiation During Solar Particle Events



What Can Radiation Do to Astronauts?

Acute Effects

High dose over a short period can lead to
- Headaches
- Dizziness
- Nausea

In extreme cases, acute effects can be severe
- Directly through radiation sickness
- Indirectly, as from vomiting in space suit

Long-term Effects

Lower dose over prolonged period can have long-term impact
- Increased risk of cancer
- Genetic or fertility impact
- Development of cataracts

How Serious Is the Threat

- Acute effects are possible (but unlikely)
  - One of largest events was in Aug 1972, between Apollos 16 and 17
  - If it had occurred while astronauts were on the lunar surface, it may have induced sickness
  - Exposure is lower in Earth orbit or within heavily shielded spacecraft
- Long term effects are unavoidable
  - Focus is on understanding increased cancer risk
- Many risks are not known
  - How does radiation affect the Central Nervous System?
  - What is the impact of radiation in a stressful, microgravity environment?
- Exposure limits may affect astronaut careers
  - Reaching monthly or annual limits could end a mission
  - Reaching lifetime limits could end a career
- To implement risk management effectively, we must know more about SPEs

Quantifying SPE Impact on Astronauts

Measure of merit for radiation impact on astronauts is the dose equivalent, which is related to the total absorbed dose by a quality factor that takes into account the relative cancer risk of neutrons and high Z primary and secondary particles

Dose Equivalent (H) for an astronaut exposed to SPEs depends not only on the external environment and shielding but also on the location within the body, due to its self-shielding

It is therefore calculated for several locations, such as to the blood forming organs (BFO), skin, eye, breast, and other tissues

Low-Earth-Orbit limits are established for BFO, Skin, and Eye

These are assumed to be upper limits…not to be exceeded

Guiding principle is ALARA: As Low As Reasonably Achievable

SPE Forecast Requirements

- SPE forecasts have no credibility today
  - Inability to forecast ahead of event (high false alarm rate)
  - Flux and fluence nowcasts are no better than order of magnitude estimates
  - Time projections are no better than climatology
- As a result, there are no operational requirements for SPE forecasts
- Operational community would like*:
  - Forecast
    - 10 to 12 hour forecast prior to a likely event
  - Nowcast
    - 6 to 8 hour forecast of magnitude and slope after event on-set
    - 3 to 4 hour rolling forecast as SPE progresses
- Realistic expectations over next few years
  - 8 hour rolling forecast as SPE progresses
  - Predict, at event on-set, the time of arrival and magnitude of shock-enhanced peak
  - Reliably forecast 3 to 7 day "all clear"

* 1996 Interagency workshop on SPE Risk Management

What Can LWS Contribute to Radiation Risk Reduction

Better understanding of SPEs

- What are the details of the acceleration mechanism
- How does the ambient medium influence SPEs
- How large can they be (what is a "worst case")
- How do SPEs vary with longitude, distance from Sun

Better forecasts of SPE evolution after on-set

- Time to and magnitude of peak flux
- Time to and magnitude of shock enhanced flux

Dynamic forecast of geomagnetic cutoff

Prediction of SPEs before on-set

Prediction of "all clear" periods

How Will This Help the Astronauts

Better understanding of SPEs

- Improved design of habitats and shelters
- Higher confidence in mission planning

Better forecasts of SPE evolution after on-set

- Higher confidence in exposure forecast
    - Implementation of more flexible flight rules
- Reduced period of uncertainty
    - Greater EVA scheduling flexibility
    - Less down-time of susceptible electronics

Dynamic forecast of geomagnetic cutoff

- Identification of ISS EVA windows of opportunity
    - Greater EVA scheduling flexibility

Prediction of SPEs before on-set

- Higher confidence in exposure forecast
    - Greater mission schedule assurance
    - Less down-time of susceptible electronics

Prediction of "all clear" periods

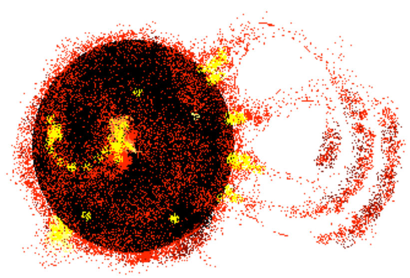
- Higher confidence in exposure forecast
    - Greater EVA scheduling flexibility
    - Greater mission schedule assurance

⇒ **Improved Safety and Enhanced Mission Assurance**

Functional Elements

Observe the Sun

Monitor solar activity to support forecasts of pending or on-going SPEs



Observe the Heliosphere

Monitor solar wind and magnetic field to support models of SPE propagation

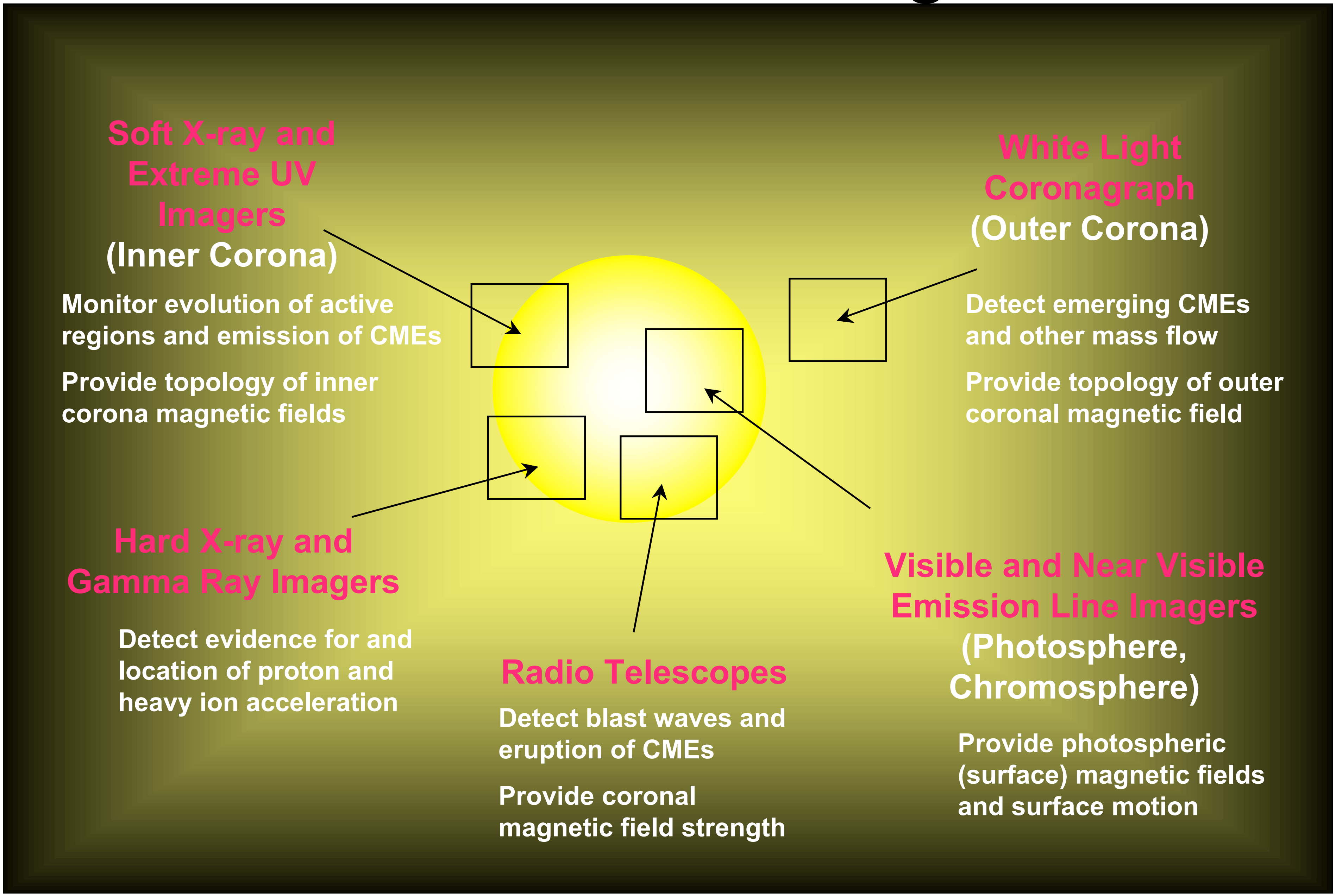
Measure Energetic Particle Flux

Provide real-time detection of increased radiation flux

Provide Communications Links

Deliver the right data to the right places

Solar Monitoring



Solar Monitoring

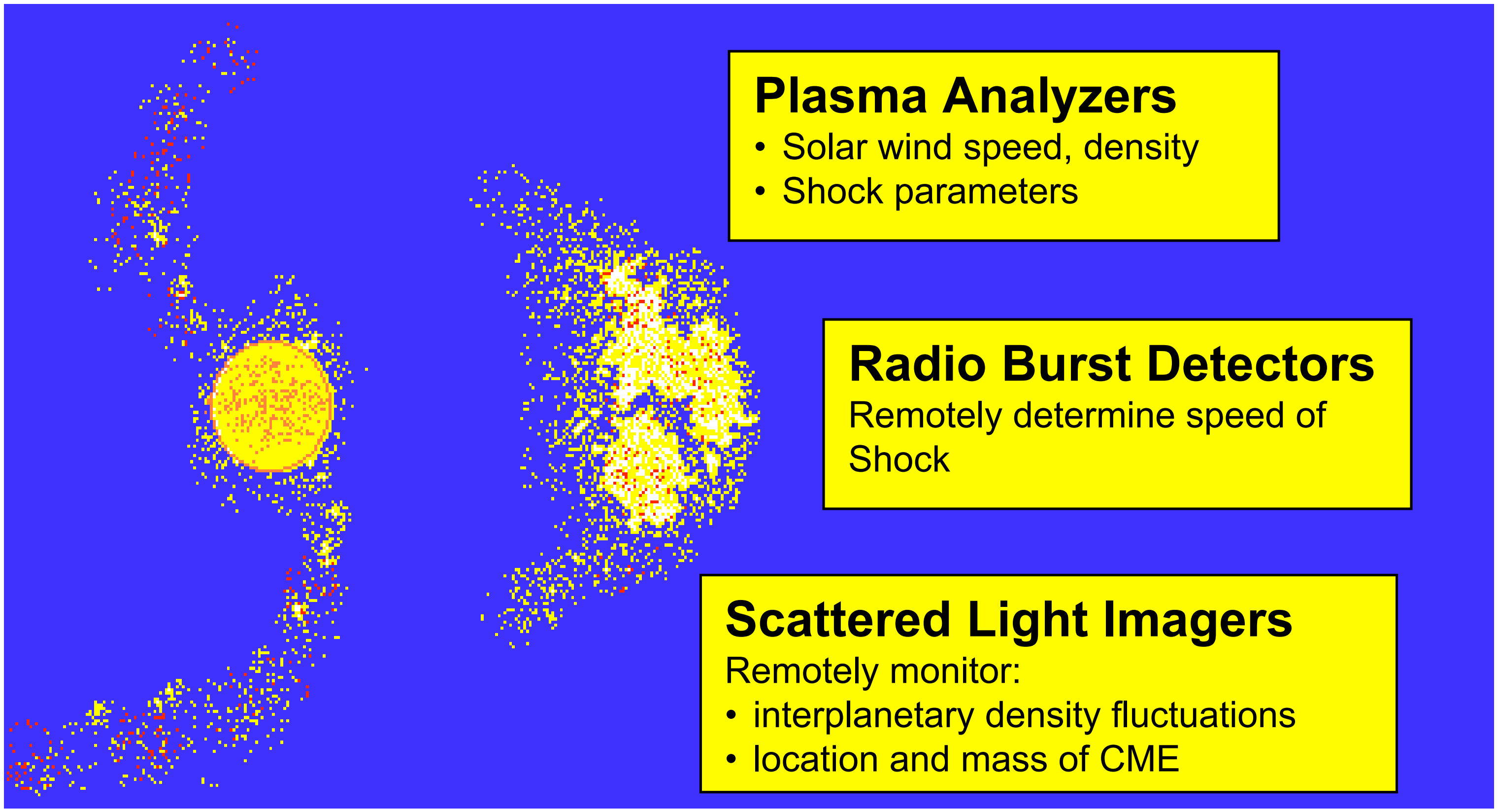
Solar monitoring is required to place the forecasts and observations of SPEs into a context of ongoing and potential solar activity

Near-real-time observations of solar active regions and emerging Coronal Mass Ejections (CMEs) may provide data useful to project the progress of an SPE over a period of hours to days

Additional progress in understanding the physics of CMEs may lead to a multiday forecast of the probability of an SPE

LWS Solar Dynamics Observatory and the “Far Side” Sentinel Mission can build on current and planned suite of research spacecraft and ground-based facilities to provide understanding and experience from which we will be able to select the appropriate operational instruments for solar monitoring

Heliospheric Monitoring



Heliospheric Monitoring

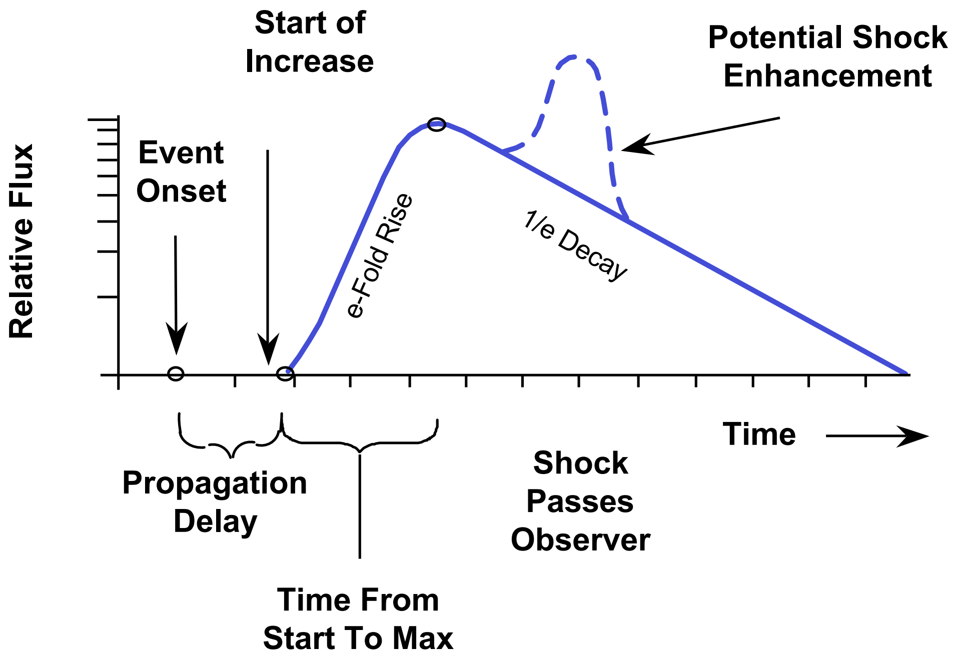
Heliospheric observations provide information necessary to model or monitor the propagation of solar energetic particles from the source to the astronauts

The data that may be necessary for SPE propagation models include

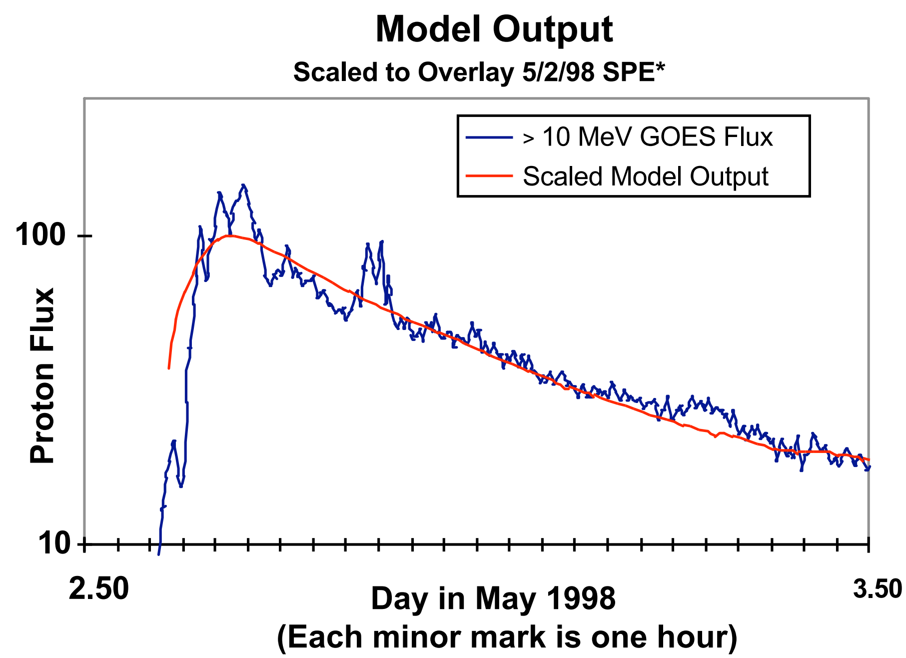
- State of the ambient solar wind plasma
- Interplanetary magnetic field
- Local disturbances moving through the inner heliosphere

LWS Sentinel Missions will provide experience and proof of concept from which we will be able to learn more about the underlying physics and select the appropriate operational instruments for solar monitoring

Measure Energetic Particle Flux



Peak flux during an SPE may be two to five orders of magnitude greater than background, within hours of the event onset



*This was not a fit to the 5/2/98 event.
The event is used only to illustrate results.

Measure Energetic Particle Flux

Direct measurements of *in situ* solar energetic particles will continue to provide the most important contributions to an SPE risk management strategy

Measurements at the astronauts' location will be able to confirm that a solar particle event is underway and to provide information about the flux, rate-of-change of flux, and total fluence of the event

In addition, instruments may be needed to measure the relative contribution to the total flux from particles with different energies, from ten MeV through several hundred MeV

Finally, it may be necessary to identify the flux of high energy, high mass ions that make up an on-going SPE

A variety of instruments are available to provide these measurements, including particle telescopes, solid state detectors, and proportional counters

Measure Energetic Particle Flux

Additional energetic particle measurements at locations significantly away from the astronauts may also contribute to forecasting the evolution of an on-going event

The complexity of shielding, uncertainties in the flux, and the need to know the crew exposure as well as possible will require real-time dose and dose rate measurements in the habitats and space suits to substantiate the modeled dose estimates and the projections that are based on measures and forecasts of the external environment

Techniques for dose and dose rate measurements will evolve from techniques used today and planned for use on International Space Station

Communications

The communication infrastructure is an important factor to consider in the construction of a total SPE warning system for two main reasons: cost and timeliness

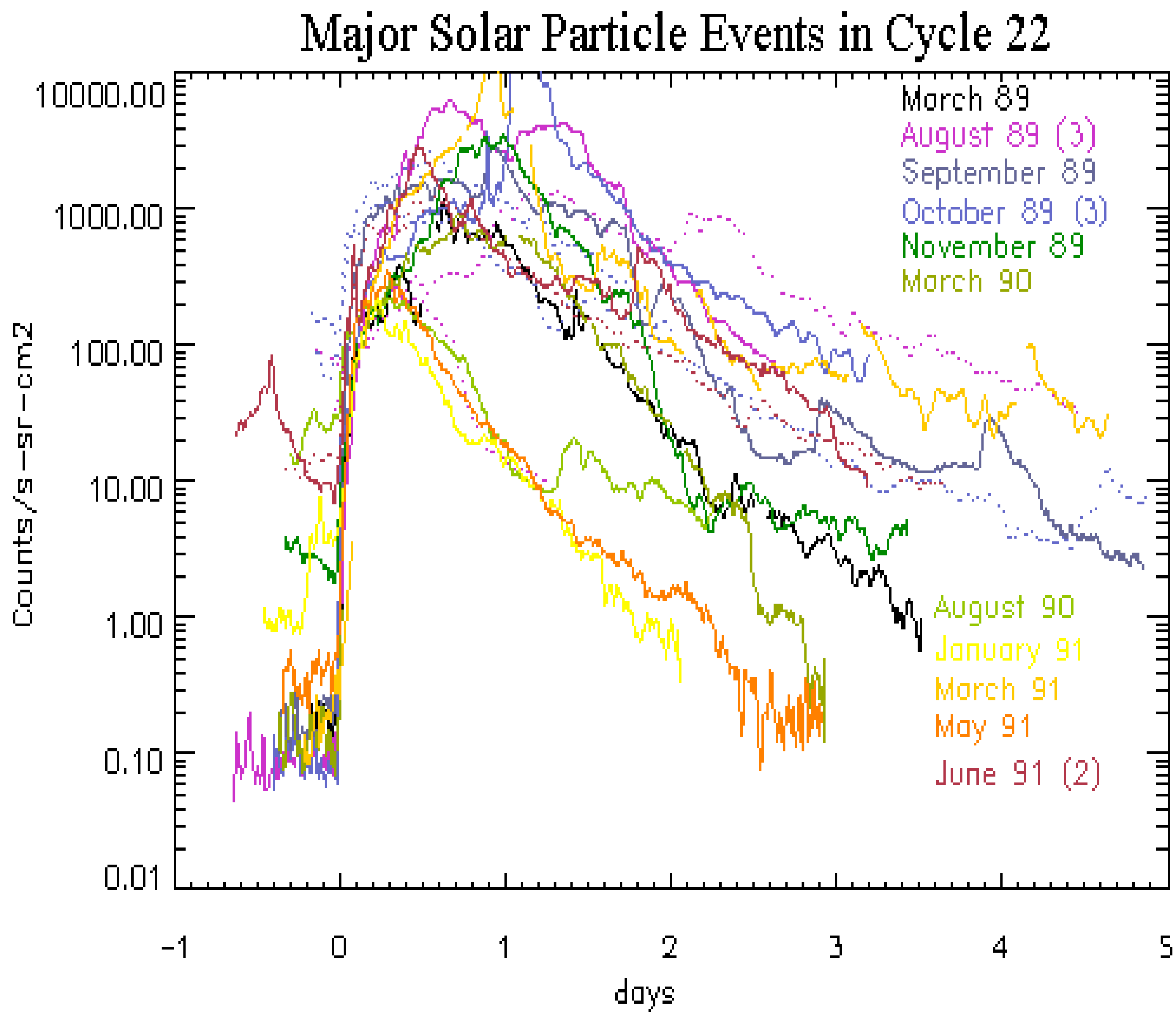
Some of the elements of an SPE architecture may be located far from Earth; Trade-offs are needed to allocate the costs of potentially high data rate transmissions between the sender and the receiver

On a Mars mission, the communication to the astronauts will take up to 20 minutes to arrive from Earth

Since the highest energy particles move with speeds close to the speed of light, techniques are needed to ensure that warnings and support are provided in a timely fashion

These issues will be addressed and solutions tested in the NASA STEREO mission and the LWS Sentinal missions

Background


Major Solar Particle Events in Cycle 22
March 89
August 89 (3)
September 89
October 89 (3)
November 89
March 90
August 90
January 91
March 91
May 91
June 91 (2)
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
Counts/s-sr-cm2
-1
0
1
2
3
4
5
days

Estimated Free-space Radiation Exposure for Cycle 22 SPEs